

Cassini Observes the Earth with Ku-band Radar and Radiometry

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ABSTRACT

In this paper, we discuss the passive and active Ku-band observations of the Earth made by the Cassini RADAR during its Earth swingby. The brightness temperature data show an abrupt transition at the ocean-land boundary, and more subtle details over South America. The backscatter data show a low wind region off the west coast of South America, consistent with QuikSCAT observations, followed by higher backscatter levels over the land area.

INTRODUCTION

On August 18, 1999, the Cassini spacecraft flew by the Earth to obtain a gravity assist on its journey out to Saturn. The Ku-band RADAR and radiometer instruments were operated over the South Pacific ocean and over South America. [1] [2]. The data collected offer a unique opportunity to compare and cross-calibrate the Cassini RADAR with Earth orbiting sensors. In the next section, we show the Cassini Radiometer data and discuss the preliminary calibration model applied to derive brightness temperatures. Following this, we show backscatter data from the RADAR and compare with measurements made by the QuikSCAT mission at the same location, and nearly the same time.

Fig. 1 shows the ground track of the Cassini RADAR beam during its 11 minute data take. Fig. 2 shows the corresponding range and incidence angle variation. The range variation caused the azimuth spot size to vary from 41 km at the beginning to 99 km at the end.

Cassini maintained a fixed sun-pointed attitude during the flyby which resulted in considerable variation in the look geometry. The incidence angle varied from 33 deg. at the start of the RADAR data collection, down to about 6 deg., and then back up to 15 deg at the end. The Cassini RADAR is setup

to collect linearly co-polarized backscattered power, however, during the Earth flyby the polarization varied from mostly H-pol at the beginning, to all V-pol about 7 minutes into the data take, and then back to mostly H-pol by the end.

RADIOMETER DATA

The Cassini RADAR has a passive total power radiometer mode that can operate by itself, or concurrent with the active modes to collect Ku-band brightness data. The radiometer integrations occur at the end of each burst after the active mode echos have been received. The radiometer bandwidth is 100 MHz which gives a theoretical stability of 0.01% for a one second integration. During the Earth flyby, the integration time in reported measurements varied from 3.7 seconds to 0.4 seconds. The total system noise was determined to be 574 K which gives a measurement stability ranging from 0.03 K to 0.09 K.

Calibration of the radiometer measurements is broken into two subproblems; calibration of the receiver, and calibration of the front end chain consisting of the high gain antenna (HGA) and all of the connecting waveguides that bring the signal back to the receiver. The receiver chain is calibrated using measurements of two internal references. One is an ambient temperature matched resistive load, and the other is an effective high temperature from a noise diode. Fig. 3 shows the normalized radiometer data from the two internal loads and from the antenna. Physical temperatures of these components and many other elements of the spacecraft and RADAR instrument are obtained from telemetry data. Normally, the noise diode effective temperature would be calibrated using data taken while observing the microwave background at 2.7 K shortly before and after the target observations. During the Earth flyby, the RADAR instrument was only operated while observing the Earth, so we used cold sky data from an earlier instrument checkout to calibrate the noise diode. An alternative calibra-

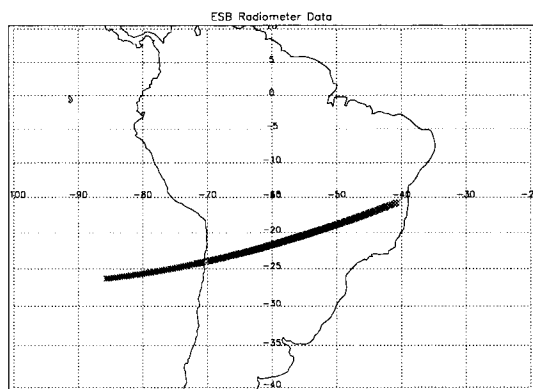


Figure 1: Cassini RADAR ground track.

tion strategy which used the cold sky background to calibrate the noise equivalent temperature of the receiver instead of the noise diode was also employed. The results were nearly identical indicating that the receiver and noise diode are both stable.

The front end chain is calibrated using temperature telemetry from various locations along the chain, and pre-launch loss measurements of the sections of waveguide. The radiating efficiency of the HGA at Ku-band is not known, and the Earth swingby offers the first opportunity to constrain this value. Future instrument checkouts will provide additional data from known sources (eg., the sun and Jupiter) to further constrain the front end model. After calibration, brightness temperatures are obtained for the source viewed by the HGA. Fig. 4 shows the brightness temperatures obtained when the loss of the HGA is assumed to be 1 dB. The ocean-land crossing is dramatic because the smoothness and high dielectric contrast of the ocean surface make it a good reflector (and a poor emitter) at Ku-band, while the rough lower contrast land surface is a poor reflector (and a good emitter). The brightness temperature levels over the ocean (about 136 K) are consistent with expectations for Ku-band measurements in clear sky conditions [3].

RADAR DATA

During the Earth fly-by, the RADAR was operated as a scatterometer with a chirp bandwidth of 106 KHz, and a pulse width of 500 μ s. The echo signal + noise and noise only powers are averaged over a burst (8 pulses) and subtracted to yield estimates of the echo signal power. Geometric factors in the radar equation (range and projected area) are then applied to generate data proportional to the backscattering cross-section σ_0 . Internal calibration data were not available for this data set, so a final absolute calibration was not possible. Instead, we scaled the data to match the levels of QuikSCAT data collected over the same area.

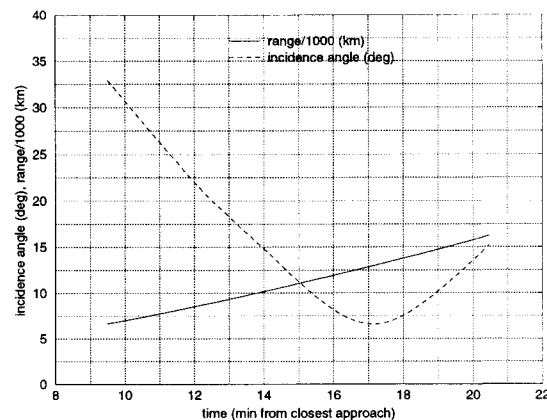


Figure 2: Variation of range and incidence angle during the flyby. Note that range is plotted in km divided by 1000.

Fig. 5 shows the Cassini RADAR scaled signal powers plotted against co-located QuikSCAT σ_0 . The brightness temperature data from the Cassini Radiometer are also plotted (scaled to fit) for comparison. The QuikSCAT data were assembled from the day before and the day after the Cassini flyby (plotted separately). Most of the Aug 17 QuikSCAT data comes from an orbit that occurred 5 hours before the Cassini flyby, while most of the Aug 18 data were collected 5 hours after the flyby. Some differences between the two instruments need to be kept in mind when comparing their data. The SeaWinds instrument on QuikSCAT is a conically scanned scatterometer which produces data at a fixed polarization and incidence angle. The data shown are VV, with an incidence angle of 54 deg. As mentioned earlier, the incidence angle and polarization varied considerably for the Cassini RADAR measurements.

Despite these differences, the two data sets show general agreement. The Cassini backscatter data clearly show a low wind area off the coast of South America which is also visible in QuikSCAT data. The low wind area appears to have moved towards the west coastline during a span of 10 hours. The QuikSCAT backscatter and Cassini Radiometer measurements show an abrupt increase when crossing from ocean to land. The Cassini RADAR backscatter levels increase before the land crossing most likely because the incidence angle is dropping below 20 deg. at this point. We also see two spikes in the Cassini RADAR backscatter levels near the minimum in the incidence angle (6–8 deg.) which may be coming from specular reflections from locally mountainous topography. Additional information can be seen at the web site set up by R. Lorenz [4].

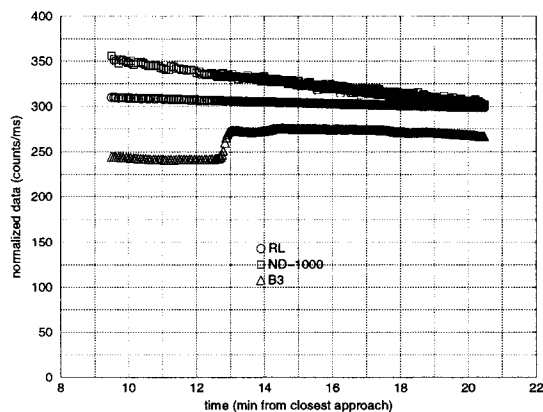


Figure 3: Normalized radiometer data.

CONCLUSIONS

In the future, the Cassini Radiometer will map the surface brightness of Titan (the largest moon of Saturn) looking for clues about the surface composition and topography, and mapping out any oceans present. The active RADAR modes including scatterometry, altimetry, and SAR imaging will map the surface at resolutions down to a few hundred meters. The Earth swingby results show that the Cassini RADAR is ready for its mission of exploration at Titan.

ACKNOWLEDGMENTS

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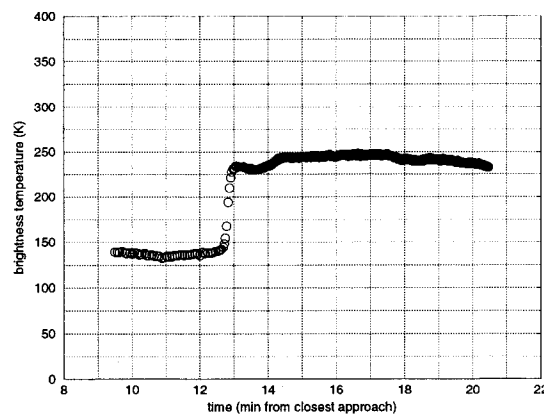


Figure 4: Calibrated brightness temperatures.

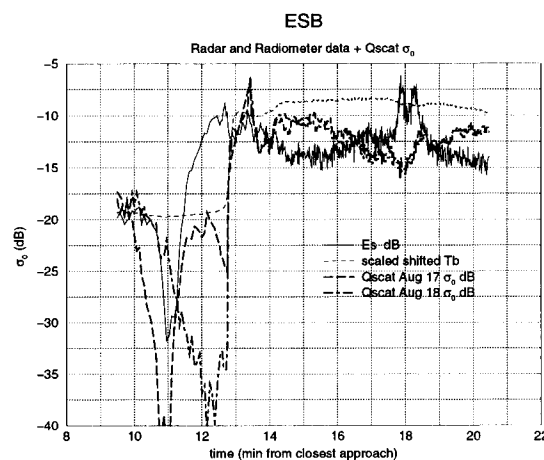


Figure 5: Cassini RADAR signal levels (E_s) and brightness temperatures rescaled and plotted against QuikSCAT σ_0 measurements.